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Dores—a three-tier ontology for modelling crises in the digital age

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# DoRES — A Three-tier Ontology for Modelling Crises in the Digital Age

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## ABSTRACT

During emergency crises it is imperative to collect, organise, analyse and share critical information between individuals and humanitarian organisations. Although different models and platforms have been created for helping these particular issues, existing work tend to focus on only one or two of the previous matters. We propose the DoRES ontology for representing information sources, consolidating it into reports and then, representing event situation based on reports. Our approach is guided by the analysis of 1) the structure of a widely used situation awareness platform; 2) stakeholder interviews, and; 3) the structure of existing crisis datasets. Based on this, we extract 102 different competency questions that are then used for specifying and implementing the new three-tiers crisis model. We show that the model can successfully be used for mapping the 102 different competency questions to the classes, properties and relations of the implemented ontology.

## Keywords

Crisis Ontology, Situation Awareness, Emergency Model, Events, Reports.

## INTRODUCTION

In emergency crises a large amount of information is collected, processed and analysed in order to help individuals and humanitarian organisations to better understand situations. Typically, information is managed through a software platform that helps responders to find key information quickly and efficiently. This means that collected information needs to be understandable by both computer software and humans.

Data is generally collected from different information sources or directly from individuals and then processed into reports that summarise existing information into a human readable format such as plain text. Such reports can then be used for representing the nature of crises events more formally so they can be processed automatically by computer systems.

Although multiple models and platform exist for representing and visualising the different stages involved during the representation of emergency events, the existing approaches tend to either focus on report representation or on the formal portrayal of emergency event. This means that the critical links between information sources, reports, situations and events may be lost in existing crisis models and they cannot be used efficiently by emergency management platforms.

In this paper we introduce a three-tier ontology called DoRES (*DOcument-Report-Event-Situation*) for representing the data collection of information about particular events and crises, their aggregation into reports and their formalisation into events and situations. The main idea behind our event representation is that the formalisation of events and associated resources directly comes from gathered information that is processed into reports.

We decide to develop our ontology<sup>1</sup> based on the analysis of existing data structures and datasets as well as stakeholders. In particular, we decide to base our model on the widely used Ushahidi crisis platform<sup>2</sup> and extend it so that it can be used for modelling a wide range of existing datasets.

Even though different methods exist for building ontologies and data models, we decide to rely on two different approaches for building our new ontology. First, we propose to partially follow the NeOn methodology (Suárez-Figueroa, Gómez-Pérez, and Fernández - Lopez 2015), a comprehensive approach for specifying, developing and evaluating ontologies. Second, we propose to apply the qualitative and structural design approach (Burel 2016) for including non-ontological resources and user studies during the specification phase of the model.

Although the proposed model may be applied to different crises and scenarios, the model is focused on providing a relatively simple model that can be easily reused and extended for specific situations. This paper also focus on the theoretical evaluation of the model as it has not been yet applied to in real world situation. We aim to test the integration of our model in a crisis platform in future work.

## DESIGN APPROACH AND METHODOLOGY

The development of the proposed model needs to follow a methodology in order to make sure that the DoRES model properly captures and apply design requirements.

### The NeOn Modelling Approach

The NeOn methodology (Suárez-Figueroa, Gómez-Pérez, and Fernández-López 2012) (Figure 1) is an approach for developing ontologies, identifying 9 different scenarios (i.e. design steps) that may arise when creating a new ontological model. As part of the creation of a new ontology, it is necessary to identify what scenarios apply to a particular development, as well as to create an Ontology Requirement Specification Document (ORSD) (Suárez-Figueroa, Gómez-Pérez, and Villazón-Terrazas 2009).

A few different methods exist for designing ontological models such as Methontology (Lopez et al. 1999), On-To-Knowledge (Staab et al. 2001), and DILIGENT (Vrandečić et al. 2005). However, we decide to focus on the NeOn approach since it helps the integration of existing models and the reuse of non-ontological models.

As displayed in Figure 1 The NeOn methodology is divided into the following 9 scenarios:

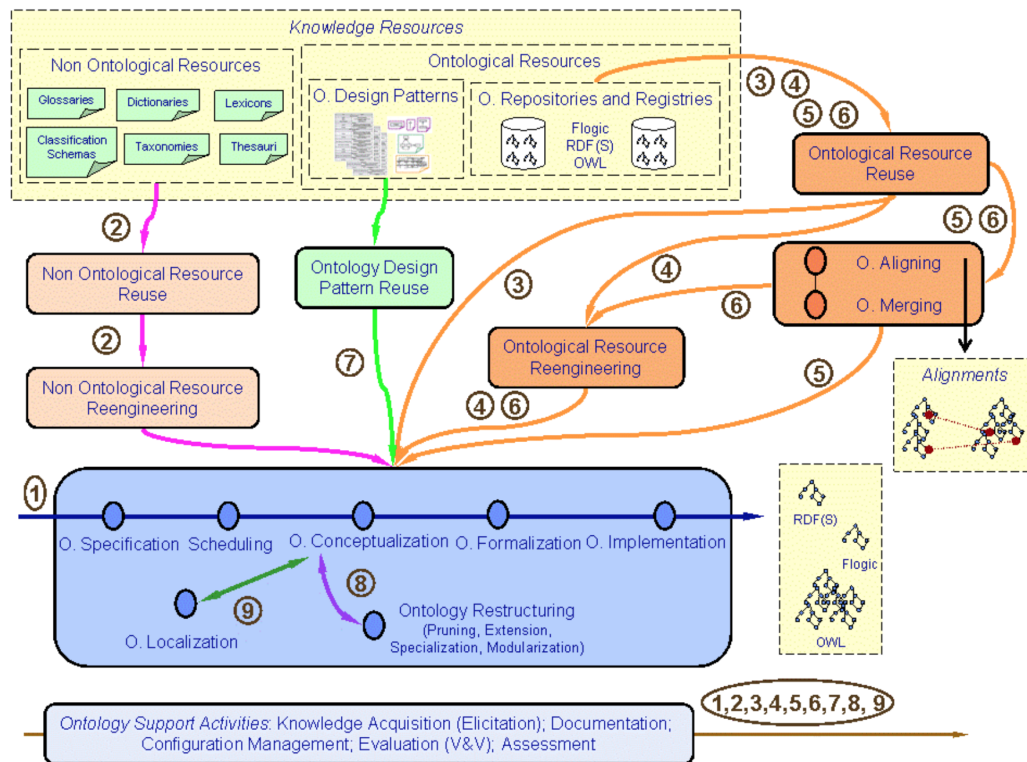
- Scenario 1: *Specification to Implementation.*
- Scenario 2: *Reusing and re-engineering non-ontological resources (NORs).*
- Scenario 3: *Reusing ontological resources.*
- Scenario 4: *Reusing and re-engineering ontological resources.*
- Scenario 5: *Reusing and merging ontological resources.*
- Scenario 6: *Reusing, merging and re-engineering ontological resources.*
- Scenario 7: *Reusing ontology design patterns.*
- Scenario 8: *Restructuring ontological resources.*
- Scenario 9: *Localizing ontological resources.*

For creating our crisis model, we have to follow the scenarios 1 and 9. To some extent we also try to reuse some commonly use ontologies as outlined in other scenarios. However, we do not strictly follow the ontology reuse scenario as it is not the focus of the DoRES data model.

The main scenario for developing the model is *Scenario 1*, as the DoRES ontological model needs to be developed from scratch. An important task of this scenario is the creation of an Ontology Requirement Specification Document (ORSD) (Suárez-Figueroa, Gómez-Pérez, and Villazón-Terrazas 2009) that describes the purpose, scope, implementation language, target group and intended uses of the specified model. In particular, this specification document needs to define a set of requirements that are defined as a set of Competency Questions (CQs). In order to create the ontology requirement specification, we need to collect knowledge from different sources and design competency questions.

<sup>1</sup>DoRES Ontology, <http://socsem.open.ac.uk/ontologies/dores>.

<sup>2</sup>Ushahidi Platform, <http://www.ushahidi.com>.



**Figure 1. Scenarios for Building Ontology Networks** (Image source: Suárez-Figueroa, Gómez-Pérez, and Fernandez - Lopez 2015).

Although the second scenario is in principle designed to help the integration of non-ontological data, it focuses on glossaries, dictionaries, lexicons, classification schemes and taxonomies, and thesauri. This type of resource is wildly different from the ones we are integrating when designing our model (i.e. highly structured data). As a result, the second scenario is not really suitable for our task.

For improving the usability of the model, we use scenario 9 which mostly consists of translating ontological labels and descriptions to multiple languages.

Although the scenarios 3, 4, 5, 6, 7 and 8 could be also applied to the design of the model we decide to only focus on the previous two scenarios. Nevertheless, when possible, we try to map some of the key DoRES concepts to existing ontologies that are not necessarily designed for representing crises (e.g. SIOC,<sup>3</sup> FOAF,<sup>4</sup> DC Terms<sup>5</sup>).

### The Qualitative and Structural Design Methodology

One of the main shortcomings of the NeOn methodology is that the approach does not really consider existing data structures and datasets as part of the development process. Even though the second scenario proposes the integration of non-ontological resources, its focus is not on existing data structures but on non-practical knowledge (e.g. thesauri, dictionaries). Therefore, the NeOn approach is mostly suitable when: 1) the new ontology needs to represent or integrate completely new datasets; or 2) the new ontology needs to integrate with existing ontologies.

Although integrating existing ontologies can be seen as a type of structural analysis since it examines how existing ontological models can be used for a particular modelling task, it does not include a data format that is not already formally represented.

In this context we propose to integrate elements from the qualitative and structural design methodology (Burel 2016) where the design of a particular model is extracted from qualitative studies (e.g. interviews, surveys) and the structural analysis of datasets and the structure of existing software platforms or processes (e.g. thread structure of the data, user social interactions).

<sup>3</sup>SIOC, <http://rdfs.org/sioc/spec>.

<sup>4</sup>FOAF, <http://xmlns.com/foaf/spec>.

<sup>5</sup>DC Terms, <http://dublincore.org/documents/dcmi-terms>.

Ontology Requirements Specification Document Template	
<b>1 Purpose</b>	
	"Software developers and ontology practitioners should include in this slot the purpose of the ontology"
<b>2 Scope</b>	
	"Software developers and ontology practitioners should include in this slot the scope of the ontology"
<b>3 Level of Formality</b>	
	"Software developers and ontology practitioners should include in this slot the level of formality of the ontology"
<b>4 Intended Users</b>	
	"Software developers and ontology practitioners should include in this slot the intended users of the ontology"
<b>5 Intended Uses</b>	
	"Software developers and ontology practitioners should include in this slot the intended uses of the ontology"
<b>6 Groups of Competency Questions</b>	
	"Software developers and ontology practitioners should include in this slot the groups of competency questions and their answers, including priorities for each group"
<b>7 Pre-Glossary of Terms</b>	
<b>Terms</b>	
	"Software developers and ontology practitioners should include in this slot the list of terms included in the CQs and their frequencies"
<b>Objects</b>	
	"Software developers and ontology practitioners should include in this slot a list of objects and their frequencies"

**Figure 2.** Template for creating an Ontology Requirement Specification Document (ORSD) (Image source: Suárez-Figueroa, Gómez-Pérez, and Fernández-López 2012).

In order to use this methodology, we need to: 1) obtain requirements and perceived needs by stakeholders using interviews or surveys (qualitative phase); and 2) collect the data that needs to be represented (e.g. Ushahidi data format, social media posts) (structural phase). Following that phase, we can generate competency questions based on the analysis of the interviews and the collected datasets.

### Ontology Evaluation

Although the NeOn methodology proposes an approach for developing a requirements document, it does not offer a clear process for evaluating if the developed model fulfils the ontology requirements.

We evaluate the DoRES model by mapping competency questions to the classes, properties and relations of the developed ontological model and by verifying if there is a possible query that can be used for connecting the different ontological resources associated with a given competency question. Therefore, the evaluation is a three steps process: 1) we map the classes, relations and properties from the DoRES model to competency questions; 2) we determine if there is a path in the DoRES ontology that connect the classes, relations and properties extracted from the competency questions; 3) if each competency question can be mapped and connected successfully to the DoRES model, we conclude that the ontology successfully represent the competency questions.

### ONTOLOGY REQUIREMENT SPECIFICATION

According to the first scenario of the NeOn methodology, the first step for creating a new ontological model from scratch is to create an Ontology Requirement Specification Document (ORSD) (Suárez-Figueroa, Gómez-Pérez, and Fernández-López 2012). In order to do so, we need to collect different information.

As outlined in Figure 2, the ORSD document is divided in 7 different parts. For filling each of these parts, we use stakeholders' interviews, analyse the structure of the Ushahidi platform and different crises related datasets. We mostly follow the structure outlined by Figure 2 and use the qualitative and structural design approach for determining the requirements of the DoRES model.

### Requirements Information Sources

As part of the ORSD design, we analyse three different type of data: 1) stakeholder interviews; 2) the Ushahidi platform data structure, and; 3) the structure of different crises datasets.

### Stakeholder Interviews

Many requirements come directly from analysing the needs of existing communities dealing with emergency situations. In this context, 8 interviews were conducted in order to better understand the model requirements.

The interviews involved an ICT specialist for disaster management and 7 community leaders. Each interviewee was asked questions about how they currently use technologies when dealing with crises, and specifically *What sociotechnical requirements should be considered to design a social platform to boost communities' resilience in a disaster situation?*

From the different interviews we observed that there was a strong need for a platform and model that allows anonymous reports, privacy management, the collection of event location and reports as well as methods for searching particular events and the ability to assign tasks to reports.

Stakeholders need to create reports of incidents with geolocation, time and date, the source of the information (e.g. data source, person reporting the incident) while ensuring methods that allow anonymous reports and feedback. The reliability of information needs to be available, and reports need to be approved. It should also be possible to assign action to reports and check their status. Reports should be available in different languages if possible. Information should also be categorised (e.g. needs, resources). In term of data sources, the model should support means for adding multiple data sources such as social media (e.g. Twitter<sup>6</sup>) and SMS.

Besides the need for representing reports of event and external data, the interviews showed a strong need for identifying the reliability of information, privacy management as well as assigning tasks for solving particular issues. Therefore, the DoRES model needs to provide an easy representation for external data and for a task representation model, as well as access to management of information and its trustworthiness.

### Ushahidi Data Structures

The different data structures used in the Ushahidi platform are directly available on the Ushahidi website.<sup>7</sup>

By analysing the different APIs of the Ushahidi platform, we observe that the information associated with the Ushahidi platform data structures consists of either properties or relations. Properties are textual fields that are not shared across data structures, whereas relations are used for linking different data structures together.

In general, it can be observed that different input sources (Message) need to be integrated into the DoRES model, then converted into a standardised unit of information (Post). These posts are then categorised (Tag) or grouped (Collection). Users (User) need to be associated to documents as creators and input sources. Finally, users need roles (Role) that can be used for giving access permission to the platform data.

### Crisis Related Datasets

Many of the available crisis-related datasets and data sources come from social media and particularly Twitter.

The following table (Table 1) lists the different crisis datasets that have been investigated in this paper. The available data can be divided depending on the data that was used for building a particular dataset. We distinguish three types of data source: social media data (i.e. Twitter posts), user reports (e.g. Ushahidi, ACLED<sup>8</sup>) and news agency data (e.g. news websites). Each data types have advantages and disadvantages. Social media data is widely available, however reliability is unclear and the format is highly unstructured. Citizen reports are more scarce but potentially more useful as they are formatted specifically for describing events. Finally, news data has the advantage to be more reliable. However, such data is more likely available after an event occurs and is low-level as it is summarizing a situation.

In term of data formats, existing social media datasets tend to be based on Twitter data, therefore, they directly follow the twitter message format and contains small short text with user information and sometimes user GPS coordinates that can be used for identifying the location of particular events.

Report data is platform-specific but generally contains a title, a date, a location, a description, and a type (e.g. fire, earthquake). Sometimes there can be additional information depending on the type of report. For example, the Ushahidi instance created for monitoring the USA presidential elections of 2016 has custom fields about candidates in each reports.

<sup>6</sup>Twitter, <http://twitter.com>.

<sup>7</sup>Ushahidi API, <https://wiki.ushahidi.com/display/WIKI/Ushahidi+3.x+REST+API>.

<sup>8</sup>ACLED, <http://www.acleddata.com/data>.



**Table 1. Crisis related datasets**

Dataset	Description	Media Type	Dataset Size
Crisis Lex T26	26 crises annotated with informativeness, information type and source.	Twitter (Social Media) $\approx$ 250k Tweets	
Incident Tweets	Data collected from multiple cities in the USA and UK.	Twitter (Social Media)	$\approx$ 15M Tweets
Crisis Lex T6	6 Crises. Annotated by relatedness.	Twitter (Social Media)	$\approx$ 60k Tweets
Crisis NLP	Multiples events datasets with some computed features.	Twitter (Social Media)	$\approx$ 40M Tweets
Crisis Map (Ushahidi)	Many event report from Ushahidi deployments.	Citizen Reports (Ushahidi)	33 Events
Phoenix Data Project	Near real-time event dataset created by scrapping 400 news sources.	Event Summaries (News Agency Data Source)	Monthly datasets (expanding)
GDELT	Created in near real-time created from multiple data sources in different languages.	Event Summaries (News Agency Data Source).	Collected every 15 minutes (expanding)
ACLED	Event summaries created weekly about event occurring in Africa and Asia.	Event Summaries (Created and verified manually).	Weekly datasets (expanding)
Crisis Net	Data of crises such as diseases, political conflicts, and health.	Reports automatically generated from different data sources.	$\approx$ 1.6M Items
Relief Web	Real-time API access to reports since 1996. P	Citizen Reports (Unformatted data).	$\approx$ 54K Reports
HDX	A dataset repository that contains multiple datasets about different crises and related resources.	Citizen Reports / Event Summaries / Social Media.	4163 Datasets / 244 Locations / 804 Sources (expanding)



Finally, many of the news agency based datasets such as the GDELT, ACLED and Phoenix Data Project datasets follow the CAMEO (Schrodt and Yilmaz 2008) model that provides a taxonomy to identify the type of event mentioned as well as the actors involved.

The analysis of the crisis related datasets shows that the Ushahidi data structures already support many of the requirement of the analysed dataset except for the representation of domain specific information (e.g. Twitter posts) and rich user or event model that is mostly given by the CAMEO taxonomy and the Twitter data.

### The Ontology Requirement Specification Document (ORSD)

Based on the analysis of the previous information sources, we can create the ORSD that can be used for specifying what the DoRES model should look like.

#### *DoRES Aims and Model Purpose*

The aim of the DoRES model is to create a model that can be used for representing information sources, reports as well as the events and situations that occurs in emergency crises.

The model needs to be general enough to cover a wide variety of scenarios and therefore be flexible as it needs to model multiple types of data sources. In the case of ontological development, a flexible model needs to offer relatively loose semantics (i.e. avoid overspecialisation) so that new types of users or resources do not require important ontological modifications.

In terms of scope, the model aims to support the modelling of crises by representing information sources, reports as well as events and situations.

#### *Intended Use and Users*

The DoRES model needs to satisfy different user groups such as governmental organizations and non-governmental groups, as well as individuals. Such individuals may have many different aims and goals. The model also needs to support algorithmic needs by allowing software to assert new information themselves (e.g. trustworthiness, extracted entities).

Following the interviews with stakeholders, we distinguish four different type of users for the DoRES model:

1. *Platform stakeholders*: The individuals or organisations that supply community platforms such as Ushahidi.
2. *Local community groups*: Community members of local activist groups.
3. *Responders*: Organisations and individuals that use information gathered by platforms in order to organise the response and recovery of a particular crisis.
4. *Individuals and small citizen groups*: Individuals or small communities that are affected by a particular crisis.

#### *Competency Questions*

A key part of the ORSD is to define competency questions that define what types of queries the model should be able to support.

We define competency questions as task-oriented questions that need to be satisfied by the DoRES model. These competency questions are used for making sure that the model supports all the question-based requirements and for validating the model against the competency questions. For example the need to have *geolocation* information associated with *events* can be modelled as the following question "What is the location of an event?".

Based on the interview analysis and the study of the Ushahidi and related dataset data structures, we create 102 different competency questions.

#### *Term Glossary*

Now that we have extracted a set of competency questions, we can extract the terms that are the most used in the questions in order to help the development of the model. The idea is that the most frequent terms are key aspects of the model and need to be modelled prominently (e.g. classes), whereas infrequent term may not need to be represented as prominently in the final model.

The NeOn methodology (Pérez et al. 2008) distinguishes three different types of terms: 1) competency question terms; 2) competency question answer terms, and; 3) object terms. The competency question terms are the top words that appears in competency questions, whereas answer terms are the ones that appears in the answer of the

**Table 2. Top Terms Extracted from the Competency Question, Crisis Related Dataset and the Ushahidi Data Structures.**

Type	Term (Frequency)
Competency Question	Document (27), Event (17), User (13), created (10), Type (9), Information (8), Message (8), Collection (7), Category (6), Platform (6), Actor (6), Media (6), updated (6), associated (5), related (4), Role (4), Report (4), name (3), description (3), Source (3), language (3), Account (3), Events (3), reliable (3).
Data Structures	created (13), allowed_privileges (11), id (10), URL (10), Form (9), data (9), User (8), Type (8), updated (7), Post (6), Message (6), Media (6), Event (5), Creator (4), Posts (4), description (4), sources (4), Collection (4), Crises (4), social (4), contact (4), name (3), annotated (3).

competency questions. The object terms are the named entities that are extracted from competency questions and answers.

Since we do not have competency questions that both contain data specific questions and answers, we generate the glossary terms as follow: 1) we extract the most frequent terms appearing in our competency questions; 2) we extract the most frequent terms appearing in the data structures that we have used for creating our competency questions. The idea is that besides the terms extracted from the competency questions, the property descriptions and names of the different datasets and the Ushahidi can help the identification of the key concept and attributes of the DoRES model.

The top terms extracted from the competency questions are listed in Table 2.

## MODEL IMPLEMENTATION

Many of the datasets and data structure analysed when creating the ORSD are centred on reports and the ingestion of external documents rather than the direct modelling of events.

Reports can be used in different ways for documenting events, needs, resources and so on and form the base of the DoRES model. The advantage of using a report centred approach is that it allows a more organic gathering of information related to events without needing rigid data structures. This is particularly suitable for resilience platforms that are deployed in large variety of situations where the types of reports are context specific.

We use a situation model for documenting how events affect their environment. Typically, a situation would involve different entities (e.g. local population, building, political situation) and would define the state that was induced by the situation. For example, a building explosion (situation) would induce a particular building (entity) to be collapsed (status).

Another important component of the model is the representation of categories and collections. We distinguish collections from categories as manually user curated groups of documents and reports whereas categories are hierarchical organisation used for classifying reports and events.

For representing users and the permissions associated documents, reports and other model classes we use the concepts of roles and accounts where user hold roles that are associated with user permissions. We also use the concept of user account that are used for holding platform specific user information such as the user contribution reliability.

Finally, we add a simple model for representing tasks that can be attached to reports and assigned to users. In the following sections, we refer to the DoRes namespace<sup>9</sup> as *dores* in the following sections.

## Classes and Relations

The DoRES model is divided in different classes that separate crisis related data in four different types of information (reports, documents event and situation) and associate them with tasks as well as users. Figure 3 shows the different classes and relations of the DoRES model.

<sup>9</sup>DoRES Namespace, <http://socsem.open.ac.uk/ontologies/dores>.

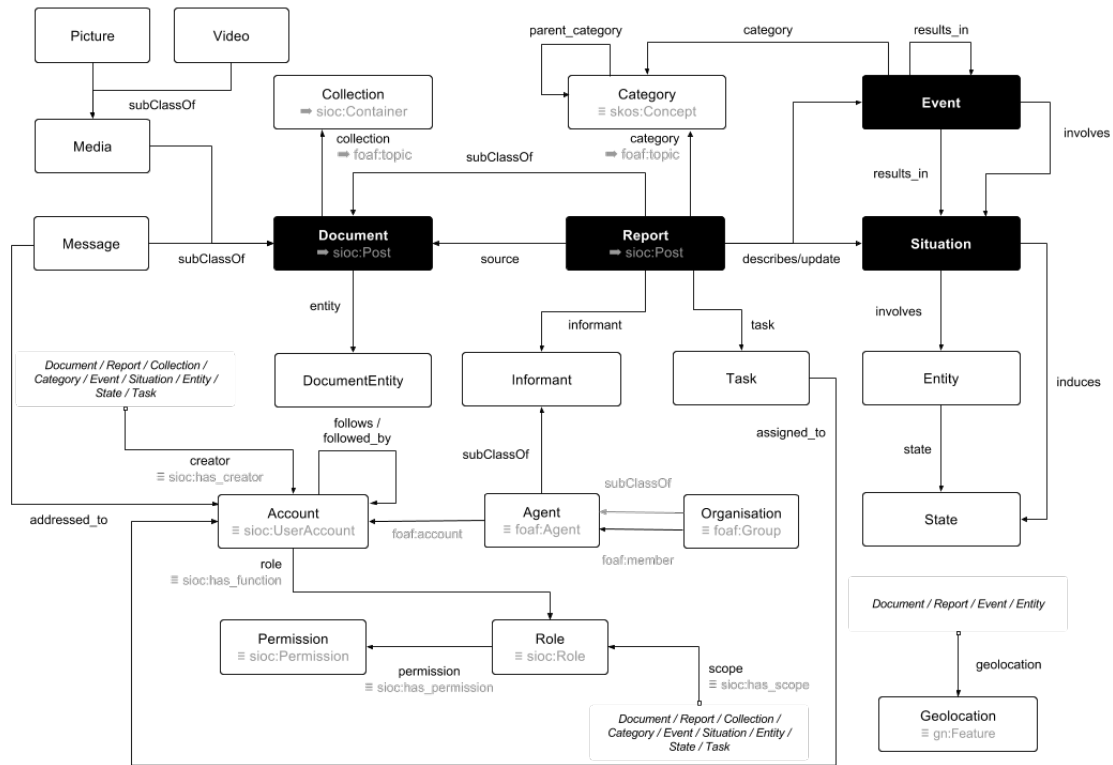


Figure 3. The DoRES Ontology classes and relations.

#### Information Sources, Reports and Situations

The competency questions show that many properties and relations are focused on different types of documents and that both the Ushahidi platform and the crisis related dataset models prefer modelling event indirectly using user submitted reports or automatically generated documents. As a consequence, we decide to centre the representation crisis related information around the concepts of `dores:Report`, `dores:Situation`, `dores:Event`, `dores:Document` and `dores:Informant`.

In order to connect each of these components, we decided to associate a `dores:Report` to a `dores:Document` that represent the information sources that were used for creating a report such as an external media (`dores:Media`) or message (`dores:Message`). These classes can be subclassed as needed if a new `dores:Document` representation is necessary. A `dores:Report` can be also linked to a `dores:Informant` that can be an `dores:Agent` or `dores:Organisation` and used for representing the organisation or person that gave the information used in a `dores:Report`.

We extend messages (`dores:Message`) from documents (`dores:Document`) as contrary to documents, messages occur in conversations (e.g. Twitter messages, forum posts) whereas documents are standalone information pieces (e.g. news articles, blog posts).

Besides associating reports to documents and informants, reports are also connected with the events (`dores:Event`) and situations (`dores:Situation`) that they are describing or updating. Events are things that happens or takes place whereas situations are used for representing the states (`dores:State`) of entities (`dores:Entities`).

The separation between `dores:Document` and `dores:Informant` with `dores:Event` and `dores:Situation` is designed for identifying how a piece of information obtained from an external source is integrated and processed through a report (`dores:Report`) into a piece of usable knowledge in the form of a situation (`dores:Situation`) or event (`dores:Event`). This allows the model to be queried from different perspectives. For instance, `dores:Document` can be used for understanding where an information comes from whereas `dores:Report` can be used for understanding how a `dores:Document` was brought in the DoRES platform and, finally, `dores:Event` and `dores:Situation` can be used for analysing current emergency situations by observing the `dores:State` of an `dores:Entity`.

Besides `dores:Document` and `dores:Message`, `dores:Report` can be also associated with different type of medias (`dores:Media`) such as pictures (`dores:Picture`) and videos (`dores:Video`).

### *Collections, Categories and Topics*

The different type of information collected by the DoRES model can be grouped and categorised in different ways. For instance, `dores:Report` and `dores:Document` can be grouped into `dores:Collection` whereas `dores:Report` and `dores:Event` can be grouped in `come:Category`.

Collections (`dores:Collection`) are directly designed to emulate the Ushahidi document collection by allowing different types of information to be grouped together as a list according to arbitrary criteria while categories (`dores:Category`) are used as a public hierarchical classification model for information retrieval purpose.

Another important part of the model is the representation of the actors, organisations and the accounts that are used for representing the creator of `dores:Document` and the person that posted a `dores:Report` as well as the people and organisation that created a `dores:Situation` or `dores:Event`.

We distinguish different types of users. In particular, we define `dores:Agent` as a generic type of user and the `dores:Organisation` class that can be used for defining different types of organisations or group a user can belongs to. For instance, a user could belong to a particular NGO or religious group.

Users (`dores:Agent`) are all defined as a subclass of `dores:Informant` that can be used as the information source of `dores:Report` when no document source (`dores:Document`) is available but when an information comes from a known individual or person.

For contributions within the DoRES model, the `dores:Accout` class is used for abstracting contributor specific information that only exist within the DoRES model such as the number of documents created by a `dores:Agent`.

### *Tasks, Roles and Permissions*

As highlighted by the ORSD, the DoRES model needs to support access permissions to the different content represented by the model. In this context, we define the class `dores:Role` and `dores:Permission` that are used together for associating permissions to multiple model classes.

The Ushahidi platform also supports the assignment of tasks to platform users. We support tasks by adding the `dores:Task` to the model and linking it to `dores:Account` and `dores:Report` so that reports can be used for assigning tasks.

### **Properties**

Contrary to relations, properties are not associated with other classes of the DoRES ontology. The 58 properties required for each classes can be directly extracted from the competency questions as well as the previously analysed data structures. Due to lack of space we do not describe the properties in this paper. However, each property is described in the ontology description that can be accessed by accessing the ontology namespace.

It is important to note that the reliability of the different elements of the ontology are not represented as properties. Instead, the reliability and trustworthiness of resources is represented using the Veracity ontology (Burel et al. 2010).

### **Integration with Existing Ontologies**

As displayed in Figure 3, the DoRES model reuse multiple ontologies for modelling the different classes, properties and relations discussed in the previous section.

### *Crisis Related Ontologies*

Although many ontologies have been designed for representing crises or related information, most of them do not focus on the concepts of report and document. Rather than using those concepts, existing models prefer focusing on the event representation of emergency crises and ignore the collection of evidences and user submitted reports as a mean for representing event related information. Task representation is also generally absent from crisis related ontologies.

The proposed three-tier design allows the model to be integrated in typical digital emergency platforms workflows by fully supporting the collection, analysis and formalisation of input data. For instance, a particular information can be uploaded on a platform by an individual (`dores:Post`), then analysed by an NGO (`dores:Report`) and then formalised (`dores:Event/dores:Report`) so that it can be queried and visualised effectively (e.g. visualisation of a situation evolution, identification of available and unavailable resources). Existing models prefer to focus on

only one or two of these aspects whereas the DoRES ontology provide a complete end-to-end model that can be integrated and enhance existing crisis platform workflows.

Many ontologies have been designed for modelling event in crises situations such as MOAC (Management of a Crisis)<sup>10</sup> and HXL (Humanitarian eXchange Language). However, despite modelling resources, processes, damages, and disasters (fire, people trapped, medical emergency), these models do not provide representations for documents and reports. The need for more complete models was highlighted by Liu et al. (Liu et al. 2013). Moreover, existing semantic models were mostly designed for providing a static view of emergency situation, where elements are captured but not their temporal evolution. Non-ontological models have been also developed such as the Disaster Management Metamodel (Othman and Beydoun 2013) and the Crisis Metamodel (Bénaben et al. 2008) that both provide frameworks for modelling situations, tasks and resources in a crisis. However as with the previously mentioned models they tend to ignore the data collection and the reporting phases that are modelled in the DoRES ontology.

In term of document representation, the CURIO ontology<sup>11</sup> (Collaborative User Resource Interaction Ontology) provides means for representing the collection of documents in an emergency context. However, the model only provides a simple model of event without the concept of event situations. However, the CURIO ontology shares some similarities with the DoRES model as it is reusing many concepts from the SIOC ontology (Breslin and Decker 2006).

### Other Ontologies

Most of the ontologies reused in the DoRES ontology are based on widely used ontologies. The main reason for reusing such kind of ontologies is that it improves the usability of the model by allowing it to be used similarly to existing ontologies.

The DoRES ontology reuses five different ontologies for modelling its components and properties. The main ontology reused for representing the different elements of the DoRES model is the SIOC ontology (Breslin and Decker 2006) that provides constructs for representing online communities. We reuse the SIOC ontology for representing documents, reports, collections, permissions and roles as well as a different properties and relations of the model.

We also reuse the FOAF (Friend Of A Friend) ontology for representing users in the model as it integrates well with SIOC and provides ways for representing agents and organisations.

For modelling geolocation, we use the Geonames<sup>12</sup> and WGS84<sup>13</sup> ontologies as they provide basic representations of geolocation coordinates that can be used for identifying the location of events and other resources.

The Dublin Core model is also used as it provides many properties, relation and classes specifically designed for modelling documents. Finally, for representing the trustworthiness of the different content of the platform we use the Veracity ontology<sup>14</sup> (Burel et al. 2010) as it provides methods for asserting the reliability of different resources.

## MODEL VALIDATION

In order to evaluate the DoRES ontology, we first extract the key classes, properties and relations associated with each competency questions. Then, we check if a path exists between each element of the extracted properties, relations and classes. Finally, we assert if a competency question is validated based on the path existence.

For each competency question, we list the classes and relations that needs to be connected and evaluate if the competency question is validated (i.e. if there is a path between the classes, relations and properties associated with the competency question).

For instance the "What is the location of an event?" competency question can be mapped into DoRES as the following: `dores:Event` → `dores:geolocation` → `dores:Geolocation`.

All the competency questions are successfully represented by the model. However, it is important to note that some mappings are not directly mapped by the DoRES ontology but are inferred through merged ontologies. For instance, the topic of `dores:Message` is not modelled directly by the DoRES model but can be represented through the `sIOC:topic` relation.

<sup>10</sup>MOAC, <http://www.observedchange.com/moac/ns>.

<sup>11</sup>CURIO, <http://purl.org/net/curio/ns>.

<sup>12</sup>Geonames Ontology, <http://www.geonames.org/ontology>.

<sup>13</sup>WGS84 Ontology, <https://www.w3.org/2003/01/geo/#vocabulary>.

<sup>14</sup>Veracity Ontology, <http://purl.org/net/veracity/ns>.

## CONCLUSIONS

We introduced the DoRES ontology as a model that helps the representation of events and related information during emergency crises. We based the development of the model on the NeOn methodology (Suárez-Figueroa, Gómez-Pérez, and Fernández-López 2012) and on a qualitative and structural design approach (Burel 2016) and evaluated the DoRES ontology by mapping competency questions to ontology properties, relations and classes.

After creating an Ontology Requirement Specification Document (ORSN) (Pérez et al. 2008), we implemented the model using semantic web technologies (RDF/OWL) and tried to link the newly developed data structures to existing ontologies such as FOAF and SIOC.

We validated the DoRES ontology by mapping competency questions to the DoRES ontology properties, relations and classes.

In future work, we plan to apply our model to real world crisis situations to see how it behaves in the field by integrating it into a community resilience platform. We also aim to develop domain knowledge that can be used with the DoRES ontology.

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